



**CONESTOGA-ROVERS
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MEMORANDUM

TO: Tom Moe, U. S. Steel
FROM: Brian Sandberg/sb/5 *BSS*
CC: Jon Christofferson, CRA
Hongze Gao, CRA
RE: Groundwater Flux Analysis
U. S. Steel's Minntac Tailings Basin
Mountain Iron, Minnesota

REF. NO.: 053103
DATE: January 25, 2010

Based on a conference call on Friday January 15, 2010 between U. S. Steel (Tom Moe), B. A. Liesch & Associates (Mike Johnson) and Conestoga-Rovers & Associates (CRA) (Brian Sandberg and Jon Christofferson), U.S. Steel directed CRA to perform a groundwater flux analysis along a 25,000 ft. wetted perimeter of the Minntac Tailings Basin. This groundwater flux analysis intends to estimate the volumetric rate of groundwater leaving along the wetted perimeter portion of the Minntac Tails Basin. CRA understand that this flux analysis will be used to assist in the Minntac Tailings Basin water and sulfate mass balance analysis.

An aerial Site Plan is provided as Figure 1.

FLUX ANALYSIS APPROACH

Groundwater flux analysis utilizes the Darcy's Law which is written as:

$$Q = KiA$$

where Q is the volumetric flux (ft^3/min). The parameter K is the hydraulic conductivity (ft/min). The unit i is the hydraulic gradient (ft/ft) and A is the cross sectional area of the aquifer (ft^2). Darcy's Law is an empirical law that defines the aquifer as a macroscopic continuum.

The flux analysis relies on three macroscopic parameters. However, there are inherent heterogeneities within the groundwater system, specifically lithological differences within the unconsolidated water table aquifer (e.g., silty sand versus gravelly sand). A brief description of the selected parameters is provided below.

HYDRAULIC CONDUCTIVITY

As described above, hydraulic conductivities vary as a result of different lithologies. These differences are evidenced in the single well response test results performed at on-site monitoring wells and piezometers. Single well response tests results are in Table 1 and range from 1.6×10^{-4} ft/min to 3.9×10^{-3} ft/min., with a geometric mean value of 1.1×10^{-3} ft/min. Because the hydraulic conductivity values vary, the flux analysis values will be presented as a range to reflect the different values.

HYDRAULIC GRADIENT

The hydraulic gradient describes the change in hydraulic head (dh) over the distance between two monitoring points (dl). However, the hydraulic gradient is influenced by the water present inside the Minntac Tailings Basin, which creates a higher hydraulic gradient. To assess this relationship, CRA used the hydraulic data compiled by STS in their Subsurface Evaluation and Seepage Evaluation Report, dated November 28, 2007. STS installed nested piezometers underneath the perimeter dike and compared that data with hydraulic measurements from piezometers and wells downgradient of the perimeter dike.

Cross section C-C, prepared by STS, shows the hydraulic relationship as groundwater moves under the perimeter dike. A copy of Cross-section C-C is in Attachment A. Using the hydraulic data from piezometer B-C-2-C and Minntac Well No. 2 (see Attachment A), there is approximately a 3.4 ft change in head between the two monitoring points that are approximately 300 ft apart. Therefore, the corresponding hydraulic gradient is **0.011 ft/ft**. This gradient value will be used for this flux analysis. However, it should be noted that once groundwater passes under the perimeter dike a portion of the groundwater discharges to the ground surface. With distance, the hydraulic gradient decreases to a lower value of approximately 0.005 ft/ft, which is the regional groundwater gradient.

AREA

The cross sectional area of the unconsolidated water table aquifer includes the wetted perimeter length of 25,000 ft. multiplied by the water table aquifers saturated thickness. For this assumption, CRA assumes that the underlying igneous bedrock formation is a low permeable barrier.

CRA reviewed boring logs and wells logs prepared by U. S. Steel, STS, and AECOM to determine the depth to bedrock along the wetted perimeter and the saturated thickness of the unconsolidated water table aquifer. In addition, U. S. Steel provided a AutoCAD drawing the identified the depth to bedrock at several locations in the Minntac Tailings Basin Area. Bedrock elevations are provided on Figure 2.

The boring/well logs show that the bedrock elevation varies across the wetted perimeter. In general, the northern wetted perimeter shows the highest bedrock elevation with an average elevation 868 ft above mean sea level (AMSL), using the Lake Superior datum, from 17 boring locations. This average bedrock location compares to the groundwater elevation at Minntac Well No. 4, which is typically measured at 867 ft AMSL. Therefore, based on the distribution of the 17 boring locations (Figure 2) approximately half of the 15,900 ft northern wetted perimeter may have very little if any saturated unconsolidated deposits. For this analysis a 5 ft saturated thickness will be applied to the segment of elevated bedrock.

The remaining half of the northern wetted perimeter may have approximately 18 ft of saturated unconsolidated deposits based on data from Minntac Well No. 4 (bottom elevation of 849 ft AMSL).

The eastern wetted perimeter shows a significant bedrock valley in the area of Minntac Well No. 2 and Well No. 3. In this area, STS well logs from B-A-1, B-A-2, B-A-3, and B-A-4 show bedrock at an elevation between 770 ft and 785 ft AMSL, with a median value of 772 ft AMSL. Groundwater at nearby Minntac Well No. 2 and well No.3 measures near 860 ft AMSL, which corresponds to an approximate saturated thickness of 88 ft. The width of the bedrock valley is uncertain as the bedrock rises up to the north and south. An estimated width of 1,500 ft will be applied to represent this 88 ft saturated zone.

South of this bedrock valley, towards Minntac Well No. 1, the saturated thickness gradually reduces to 30 ft. This 1,500 ft segment south of the bedrock valley will be given an average thickness of 49 ft., which represents the average difference between 88 ft and 30 ft.

North of the bedrock valley, this 6,100 ft segment of wetted perimeter shows the bedrock elevation rising to 844 ft AMSL and with the majority of this segment having a bedrock elevation near 840 ft AMSL. For the purposes of this flux analysis, a 20-ft saturated aquifer thickness will be applied.

GROUNDWATER FLUX RESULTS

Table 2 presents the groundwater flux results. The results are presented using the minimum, geometric mean, and maximum hydraulic conductivity values. The flux analysis shows that it ranges from 1 ft³/min to 21 ft³/min, or 6 to 154 gpm.

DISCUSSION

The groundwater flux analysis shows that volume of groundwater leaving the Minntac Tailings Basin does not appear substantial relative to the size of the facility. These results are based on the best estimates of available data. However, we recognize that variability of the aquifer properties in space, such as the variability of hydraulic conductivity and hydraulic gradient from place to place, could collectively affect these groundwater flux values by as much as an order of magnitude. Such variability of aquifer properties may only be reasonably represented using numerical models such as MODFLOW which may include other hydraulic effects such as the seepage from the toe of the Minntac Tailings Basin pool where present. A model with a realistic representation of the groundwater flow conditions in the vicinity will be able to provide a more realistic flux estimate with less uncertainty.

TABLE 1
SINGLE WELL RESPONSE TESTING RESULTS
MINNTAC TAILINGS BASIN
MOUNTAIN IRON, MINNESOTA

<i>Well No.</i>	<i>Conducted By</i>	<i>Hydraulic Conductivity</i>
1	STS	2.9 x 10-3 ft/min
2	STS	3.9 x 10-3 ft/min
3	STS	2.8 x 10-3 ft/min
4	CRA	3.8 x 10-4 ft/min
6	CRA	1.9 x 10-4 ft/min
7	CRA	2.9 x 10-3 ft/min
10	CRA	2.1 x 10-3 ft/min
PZ-1	CRA	1.6 x 10-4 ft/min
PZ-3	CRA	1 x 10-3 ft/min

Geometric Mean 1.1 x 10-3 ft/min

Notes:
STS = Soils Testing Services
CRA = Conestoga-Rovers & Associates

TABLE 2
GROUNDWATER FLUX ANALYSIS
MINNTAC TAILINGS BASIN
MOUNTAIN IRON, MINNESOTA

FLUX EQUATION

$Q = KiA$

HYDRAULIC CONDUCTIVITY (K) VALUES

1.6 X 10-4 FT/MIN	MINIMUM
1.1 X 10-3 FT/MIN	MEAN
3.9 X 10-3 FT/MIN	MAXIMUM

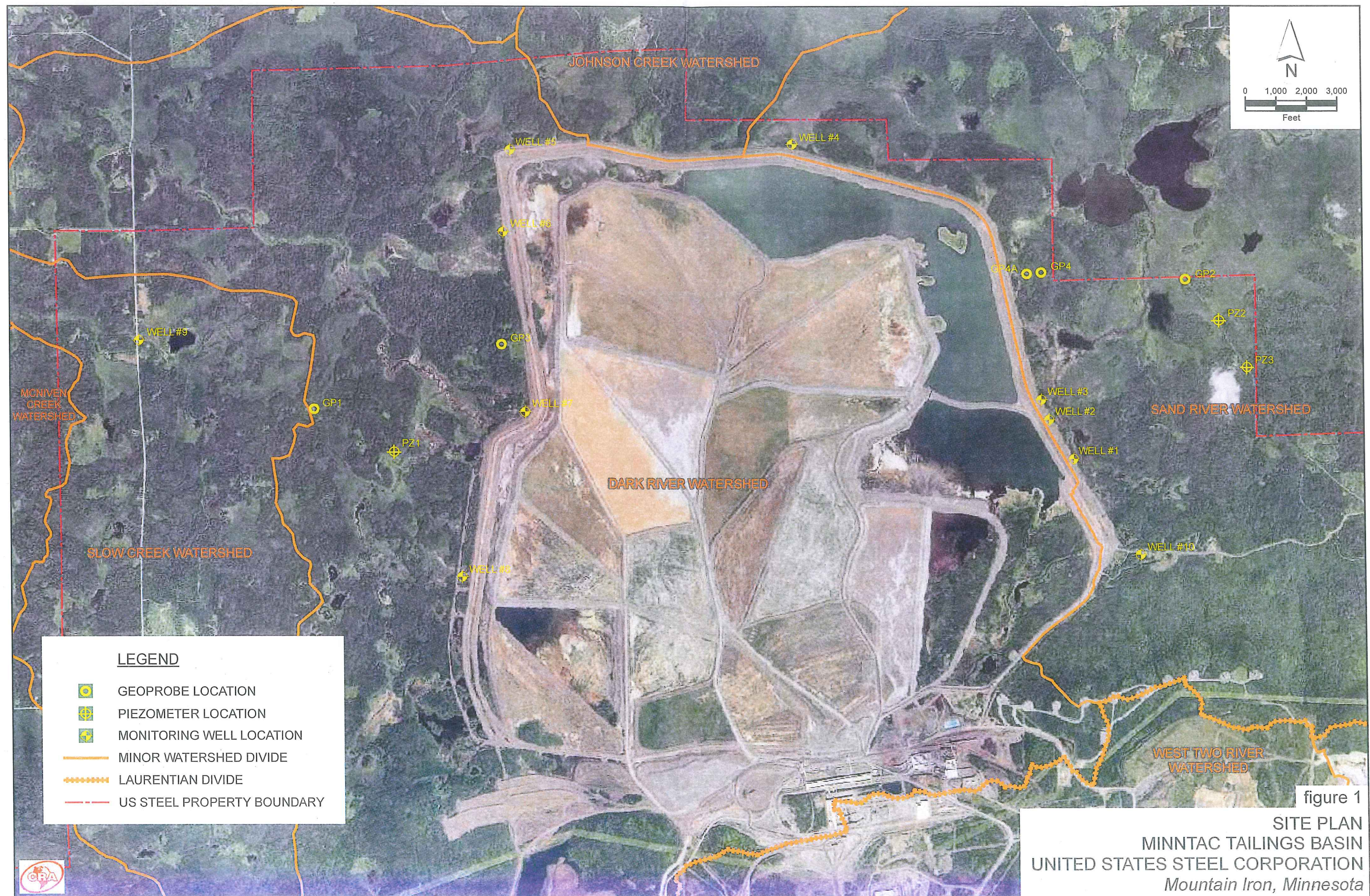
HYDRAULIC GRADIENT (i)

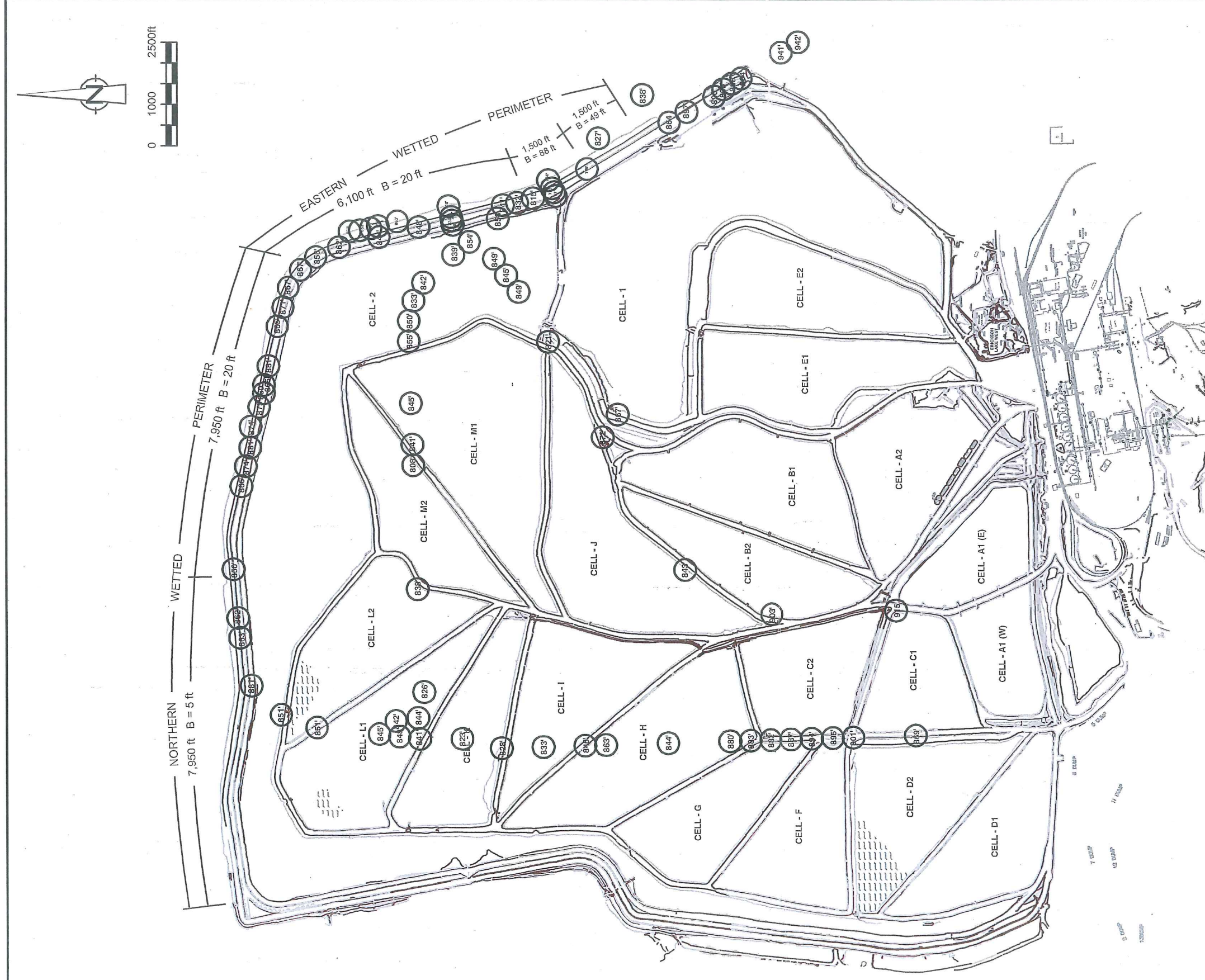
0.01 FT/FT

AREA (A)

	Length	Saturated Thickness	Area
<u>Northern Wetted Perimeter</u>	7,950 ft	5 ft	39,750 ft2
	7,950 ft	20 ft	159,000 ft2
<u>Eastern Wetted Perimeter</u>	1,500 ft	88 ft	132,000 ft2
	1,500 ft	49 ft	73,500 ft2
	6,100 ft	20 ft	122,000 ft2
TOTALS	25,000 ft		526,250 ft2

Q min.	1 ft3/min	6 gpm
Q mean	6 ft3/min	43 gpm
Q max.	21 ft3/min	154 gpm





LEGEND

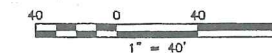
903' DEPTH TO BEDROCK BOREHOLE (LAKE SUPERIOR DATUM)

B= SATURATED AQUIFER THICKNESS

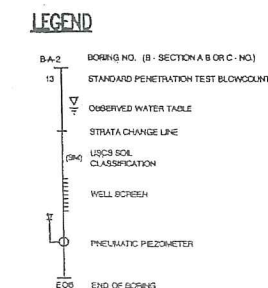
figure 2
BEDROCK BORING LOCATION
MINNTAC TAILINGS BASIN
UNITED STATES STEEL CORPORATION
Mountain Iron, Minnesota



ATTACHMENT A
STS CROSS - SECTION C-C



$$\Delta h = \frac{BC2}{\text{Well \#2}} = 3.4 \quad \Delta Q = 300' \quad i = 0.011$$



STS CONSULTANTS

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UNITED STEEL CORPORATION
MINNESOTA ORE OPERATIONS
8819 OLD HIGHWAY 169
MOUNTAIN IRON, MINNESOTA 55768

CROSS SECTION C-C'
EAST PERIMETER TAILINGS DAM
MINNTAC IRON MINE
MCINTAIN IRON, MINNESOTA

Issued	
Rev	Date
Description	

Designed: MDC 09/10/2007
 Drawn: LDJ 09/10/2007
 Checked: MDC 09/27/2007
 Approved: WHW 10/22/2007

PROJECT NUMBER
200703384

B-8

SHEET XX OF XX

SECTION C-C
SCALE: 1" = 50'

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